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Experimental study on fiber Bragg grating electric current sensor

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ABSTRACT

A new electric current sensor based on fiber Bragg grating tuned by giant magnetostrictive material rod is demonstrated in this paper. A fiber Bragg grating is firmly clung on a giant magnetostrictive rod that is put into the central part of a solenoid. The Bragg wavelength of the fiber grating will shift when the uniform magnetic field in the solenoid changes. The rod will have elastic lengthening along the direction of the magnetic field. The grating resonant wavelength of fiber grating will shift as consequence of the rod lengthening. The relationship between the electric current and the wavelength shift is basically linear. The wavelength range of linear tuning is about 0.9nm. The tuning sensitivity is about 0.001nm/mA.

Keywords: Giant magnetostrictive material, Fiber grating, Solenoid, Electric current sensor

1. INTRODUCTION

Fiber Bragg grating (FBG) sensor technology has become one of the most progressing sensing topics of this decade in the field of optical fiber sensor technology as FBG sensors are capable of measuring a wide range of parameters^{1,2}. The main reason for this is because FBG sensors have a number of distinguished advantages over other implementations of fiber-optic sensors, in particular absolute measurement, potential low-cost, flexibility, and unique wavelength-multiplexing capacity. Hence, FBG sensors are of great importance in civil, industrial and military fields.

Faraday effect is used for electric current sensing for conventional current sensors while Kerr effect or Pockels effect is used for voltage sensors³. Optical fiber sensors exploiting Faraday effect have been intensively studied. However, the practical application of optical fiber sensors cannot meet our need for problems associated with induced linear birefringence, temperature and vibration have limited the application of them. Several alternative methods have been set up in experiment to measure electric current and voltage, for example, a hybrid system that consists of a conventional current transformer and a piezoelectric element and an interferometric wavelength-shift detection method. FBGs are ideal for use in electrical power industry due to the immunity to electro-magnetic interference. A new electric current sensor based on fiber Bragg grating tuned by giant magnetostrictive material rod is demonstrated in this paper.

2. PRINCIPLE

The Bragg wavelength λ_B of the FBG is given by

$$\lambda_B = 2n_{eff} \Lambda, \quad (1)$$

where Λ is the fringe spacing of the FBG and n_{eff} is the effective refractive index.

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Both the refractive index and spacing, therefore Bragg wavelength are depended on temperature and strain. Assuming the temperature is unvarying, the strain-to-wavelength relation is given by

$$\frac{\Delta\lambda_B}{\lambda_B} = (1 - p_e)\varepsilon_{ax}, \quad (2)$$

where p_e is the effective photoelastic coefficient. ε_{ax} is the strain along the grating's axis direction. The effective photoelastic coefficient can be expressed as

$$p_e = \frac{n_{core}^2}{2} [p_{12} - \mu(p_{11} + p_{12})], \quad (3)$$

where p_{11} and p_{12} are the photoelastic coefficients of the strain tensor, μ is the Poisson ratio and n_{core} is refractive index of the fiber core. For SiO_2 fiber, $n_{core} = 1.46$, $p_{11} = 0.12$, $p_{12} = 0.27$, $\mu = 0.16$, so $p_e \approx 0.22$. According to equation (2), the Bragg wavelength can shift under an axial strain. The giant magnetostrictive material is a special kind of alloy of $\text{TbDy}(\text{FeM})_2$ system composition and a magnetostrictive rod of dimensions $5 \times 50\text{mm}$ is used in experiment as magnetic field transducer. When a magnetic field is applied to it, the magnetic domains in the magnetostictive material tend to align along the field direction and, as a result of the magnetoelastic coupling, the material suffers an elastic lengthening in the direction of the magnetic field⁴. Assuming a FBG is hold on a giant magnetostrictive rod which is placed into the central part of a multi-layer solenoid, the Bragg wavelength of the fiber grating will shift when the uniform magnetic field in the solenoid changes because the strain of the giant magnetostrictive rod will transfer to the FBG.

3. EXPERIMENTAL RESULTS AND DISCUSSION

Fig.1 is the diagram schematic of FBG sensing head. The FBG approximately 11mm in length is used in experiment, which is fabricated in Germanium-doped silica fiber by ourselves using a KrF excimer laser emitting at 248nm and a phase mask. The fiber Bragg grating with 96% peak reflectivity at 1549.02nm and 0.22nm bandwidth is used in this preliminary experiment. Fig.2 shows the experiment setup for current measurement of the sensor. Light from a broadband light source (BBS) is launched into the sensing head, the transmission light is monitored by a commercial optical spectrum analyzer (Advantest Q8383). The application of mechanical prestress will result in significance modification of its performance. The prestress will reduce the sensitivity to the magnetic field but gives a more linear response. The solenoid has about 2000 circles and the length of this solenoid is 120mm. Put the sensing head in the central part of a multi-layer solenoid and the magnitude of magnetic field is uniform in the central part. The magnitude of uniform magnetic field determined by the scope of the electric current in wax cloth windings. No mechanical prestress is applied in order to achieve maximum sensitivity to magnetic field. The relationship between the electric current and the wavelength shift is shown in Fig.3 (the dots is experimental results, the line is the fitted line).

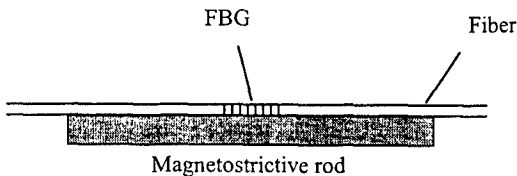


Fig.1 FBG sensing head

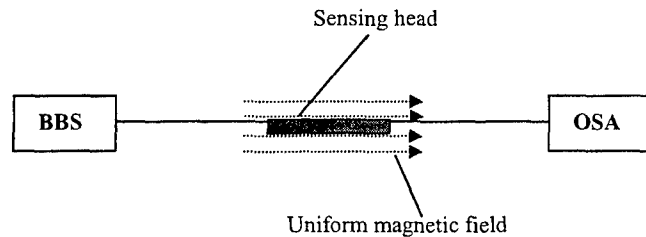


Fig.2 Schematic diagram of experimental setup for current effect measurement

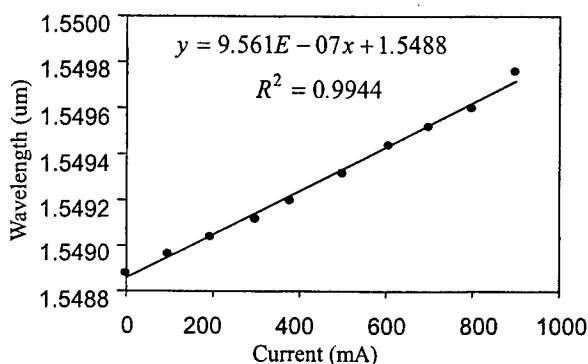


Fig.3 The relationship between the bragg wavelength of FBG and current

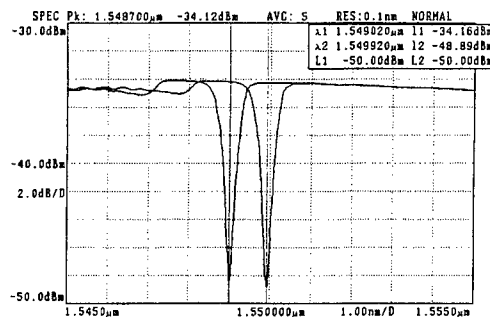


Fig. 4 The spectra of FBG at different currents

It is easy to see that the relationship between the current and the Bragg wavelength shift of FBG is basically linear ($R^2=0.9944$) in measuring range and the Bragg wavelength range of linear tuning of 0.9nm is achieved. The tuning sensitivity is about 0.001nm/mA. In preliminary experiment, we observe that Hysteresis will affect the measuring results if we go on increasing the current (more than 1A), so the measuring range of this current sensor not more than 900mA. When the current exceeds the linear operating range of the magnetostictive material, the nonlinear behavior will appear due to the saturation of the alloy. The FBG suffers no chirp in the tuning process as it is illustrated in Fig. 4.

Temperature effect must be considered if the measuring time is long. The heat created by the solenoid will accumulate and it will affect the Bragg wavelength. In experiment, we use an adiabatic pipe to protect the sensing head from heat. How to eliminate the Hysteresis and temperature effect and extend the measuring range are important questions to be resolved in our farther study.

4. CONCLUSION

A new electric current sensor based on fiber Bragg grating tuned by giant magnetostrictive material rod is proposed. The relationship between the electric current and the wavelength shift is basically linear by the regression coefficient of $R=0.945$. This device has many characteristics, such as simple structure, high sensitivity, and good linearity. It is promising to be used into in-process industrial measurement and biological sensing. It also offers a potential alternative to promote the application of optoelectronic technology for improving human health, safety and environmental protection.

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